THE ASSESSMENT OF NONIONIZING RADIATION HAZARDS

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Abstract

Naval personnel frequently occupy environments susceptible to microwave energy from weapons systems and communication devices. Several scientific reports have indicated that behavior can be modified by relatively low levels of microwave energy, but the detrimental or beneficial nature of these behavioral effects are not immediately apparent. A series of experiments employing a behavior whose affective nature could be assessed and which was analogous to human behavior was conducted with several species of animals. Rats, squirrel monkeys, and rhesus monkeys trained on operant tasks were exposed to microwave radiation and produced data suggestive of a possible extrapolation to man in similar situations. The results show that behavioral changes are related to increases in colonic temperature. In monkeys the average increase in colonic temperature associated with changes in response rate was 1 °C. Response rate did not change in the absence of concomitant temperature increases.

Introduction

Background

A major problem in evaluating the effects of any physical agent that may be potentially hazardous to man is that man himself is not likely to be the experimental subject. Selecting the most appropriate organism for testing that agent and applying the results to man then becomes an often controversial task. The traditional subject for testing the effects of nonionizing radiation, particularly radio frequency (RF) radiation, is the rat. However, generalizations drawn from rats and applied to man are especially prone to error when dealing with RF radiation. The effects of RF radiation are so dependent on the geometry and body mass of an animal that it may be impossible to position man in the same orientation to radiating sources as one does a rat. Hence, animals more similar to man are needed. One such animal is the squirrel monkey, *Saimiri sciureus*; another is the rhesus monkey, *Macaca mulatta*. These animals along with the rat provide animals of three distinctly different body masses that relate to one another on an almost logarithmic scale thereby providing one dimension for extrapolation to man.

Another problem in evaluating biological effects is choice of the dependent variable. Psychologists are continuously tasked with generalizing from behavior in animals to behavior in man. One solution is to train animals to perform a task in the same manner as required of humans. A general class of behaviors that encompass such performance is designated as operant. The present series of experiments (de Lorge, 1976; 1979; in press; de Lorge and Ezell, 1980) utilized operant behavioral changes as the dependent variable against which the effects of RF radiation were measured. In most

cases an observing response task was chosen because of its similarity to vigilance behavior in man (Holland, 1957). In other instances the results from animals performing different operant tasks (Sanza and de Lorge, 1977; Nelson, 1978, Knepton and de Lorge, 1983) will be reported.

So that the interaction of body mass and frequency of RF radiation could be examined, uniquely different frequencies were utilized in these experiments. The frequencies of 225 MHz, 1.3 GHz, 2.45 GHz, and 5.7 GHz were also chosen because of availability and because they represented frequencies in use by the Navy. The rhesus monkey of the size used in these studies has a resonant RF frequency of about 225 MHz; the other three frequencies were not only above the resonant frequencies of the rhesus but also of the rat and squirrel monkey.

The general approach of these studies was to train animals on operant tasks until stable response rates were obtained, and then expose the animals to RF radiation during their work sessions. This approach demonstrated that in all of the animals an operant response was well maintained during hour-long sessions until an animal's colonic temperature reached or surpassed a 1 °C increase above its baseline.

Method

Subjects

Rats obtained from the Charles River colonies, squirrel monkeys, Saimiri sciureus, obtained from Columbia, South America, and rhesus monkeys, Macaca mulatta, bred in our own colony were subjects. Body masses of the rats were 300-400 g, the squirrel monkeys averaged 700 g, and the rhesus monkeys ranged between 4.3 and 5.7 kg. The animals were food deprived and trained at approximately 85% of their free-feeding body mass. Body mass during sham and exposure sessions was typically somewhat higher; for example, the rhesus monkeys were maintained at 92% of their free-feeding body mass during their experimental sessions. The animals normally obtained their daily food during their sessions and were supplemented in their home cage. Water was continuously available in the home cages.

Apparatus

Four anechoic chambers differing only in basic dimensions were used for radiation exposure. The chambers were lined with pyramidal absorber, cooled with air conditioners and ventilation fans, and each was equipped with a television camera. Devices for presenting auditory and visual stimuli, food reinforcement, chamber illumination, and monitoring temperature and humidity were also located in the chambers.

RF radiation was generated by various military and commercial radar sets at .225, 1.28, 2.45 and 5.62 GHz. The .225 and 2.45 GHz sources were continous wave whereas the 1.28 and 5.62 GHz sources were pulsed at different repetition rates. Both custom-made and standard gain horns were used. In the monkey experiments the front surface of the upright seated animal was usually irradiated, but dorsal irradiation was used with one squirrel monkey

study and a rat experiment. The rats were irradiated on their right side in other studies. Colonic temperatures were obtained from the monkeys during their experimental sessions.

Procedures

Animals were initially trained in Plexiglas devices and then transferred to Styrofoam boxes in the case of the rats (Sanza and de Lorge, 1977) and chairs in the cases of the monkeys (Reno and de Lorge, 1977).

The typical operant task required an animal to respond on one of two different levers to produce stimuli or food pellets. Stimuli were randomly presented depending upon lever response rate and when the stimulus corresponding to availability of food appeared a response on the second lever produced food. The schedule of reinforcement, number of manipulanda, stimulus modality and quantity varied in different experiments. Food was the only reinforcer used and water was unavailable during the experimental sessions which lasted from 40 minutes to 2 hours. The rate of responding on the lever producing the food signal was the prime measure of performance.

In all of these experiments session-to-session response rate stability was established prior to exposure to RF radiation. Each exposure session was preceded and followed by sham exposure sessions in which conditions were identical to exposure sessions except that the magnetron was not energized.

Results

Repeated exposures of the various animals to increasing power densities of radiation revealed levels where the animals' response rates were unaffected by the radiation, intermediate levels where response rates were marginally perturbed, and levels where responding eventually stopped. It was therefore possible to establish average power densities in each animal where disruption of behavior occurred. The medians of these various power densities were then used to calculate thresholds of disruption for the various animals and different experiments.

In addition, for the monkeys, colonic temperatures were simultaneously obtained that revealed the average temperatures of the animals corresponding to the power densities that produced response rate disruption. Temperatures were also obtained in some rat experiments but not simultaneously with the experimental sessions.

The thresholds for disruption of operant responding in rhesus monkeys in terms of power densities at frequencies of 225 MHz, 1.3 GHz, 2.45 GHz and 5.8 GHz were respectively 8.1, 57, 67 and 140 mW/cm^2. Similarly, the thresholds for the squirrel monkey at 2.45 and 5.62 GHz were 45 and 40 mW/cm^2, and for the rat at 1.28, 2.45 and 5.62 GHz were 10, 28, and 21 mW/cm^2. With few exceptions these power densities were all associated with an increase in colonic temperature of 1 °C or greater in the corresponding animals.

Discussion and Conclusions

Disruption of operant behavior by RF radiation is directly associated with increases in body temperature. Local increases in temperature may be the primary determinant of such disruption but we are unable to assess this aspect at the present time.

The various threshold power densities obtained in this series of studies provides sufficient data to generate a family of curves based on different characteristics of these animals and the frequency of the nonionizing radiation. Some of these curves illustrate linear and nonlinear relationships between nonionizing radiation and body mass, body surface area or diameter of the cranial cavity. All of these curves provide some basis, albeit tenuous, for predicting similar effects on humans of RF radiation.

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